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Miocene mollusks from the Kumano Group of the Ukui area, southeastern part of the Kii Peninsula, southwestern Honshu, Japan

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Abstract. **The Shimosato Formation comprises the lower part of the Kumano Group of the southeastern Kii Peninsula, southwestern Honshu. It yields such mollusks as *Saccella miensis* (Araki), *Cyclocardia siogamensis* (Nomura), *Macoma* (*Macoma*) *izurensis* (Yokoyama), *Cultellus izumoensis* Yokoyama, *Dosinia* (*Phacosoma*) *nomurai* (Otuka), *Periploma* (*Aelga*) *mitsuganoense* Araki, *Thracia watanabei* Itoigawa and Shibata, *Turritella* (*Hataiella*) *sagai* Kotaka, and *Fulgoraria* (*Musashia*) *yanagidaniensis* Araki. The *Periploma-Saccella-Cyclocardia* and *Turritella-Dosinia* assemblages of the Shimosato Formation are inferred to represent lower sublittoral to bathyal and sublittoral environments, respectively.**

The fauna of the Shimosato Formation is comparable with the subtropical Akeyo Fauna of late Early Miocene age, based on the occurrence of diagnostic species such as *Dosinia* (*Phacosoma*) *kawagensis* Araki, *Thracia watanabei* Itoigawa and Shibata, *Turritella sagai*, and *Fulgoraria yanagidaniensis*. The assemblages of the middle part of the Shikiya Formation and the lower part of the Mitsuno Formation are comparable with those of the tropical Kurosedani (subtropical Kadonosawa) Fauna of latest Early to earliest Middle Miocene age.

Key words : Assemblages, fauna, Kumano Group, Miocene, mollusks, systematic description

Introduction

The Miocene Kumano and Owase Groups of the Nankai Geologic Province are exposed in the southeastern part of the Kii Peninsula, southwestern Honshu (Figure 1). The Kumano Group rests upon the Shimanto Supergroup with clino-unconformity or is faulted against it and is intruded by the Kumano Acidic Rocks. The age of the Kumano Acidic Rocks is between 14 and 15 Ma (Chijiwa, 1988). The Kumano Group consists largely of mudstone and sandstone from 1,500 to 4,000 m thick and is divided into three lithologic units, in ascending order: the Shimosato (Onuma), Shikiya (Koguchi) and Mitsuno Formations (Hisatomi, 1984) (Figure 2).

The contemporaneous Setouchi Miocene Series (upper Lower to lower Middle Miocene) of the Setouchi Geologic Province is extensively distributed in central and western Honshu, to the north of the Kii Peninsula (Figure 1). The molluscan paleontology of the Setouchi strata has been studied in detail (*vide* Itoigawa and Shibata, 1992). For example, Itoigawa (1987, 1988) named and defined the subtropical Akeyo Fauna (late Early Miocene ; ca. 18 to 16 Ma) based on mollusks of the Akeyo Formation of the Mizunami Group. Similar fauna has also been recorded from: the Ichishi, Ayugawa and Tsuzuki Groups of the Eastern Setouchi Miocene Series in southwestern Honshu ; the Kurami Group in central Honshu ; the upper part of the Kunugidaira Formation, and the Nakayama and Yotsuyaku Formations in northeastern Honshu (Ozawa *et al.*, 1995 ; Matsubara, 1995a).

On the other hand, the tropical Kurosedani Fauna (Tsuda, 1960) has been recorded from southwestern Japan, and the contemporaneous subtropical Kadonosawa Fauna has been recorded from northeastern Honshu and southern Hokkaido, northern Japan (Itoigawa, 1988). Both faunas are restricted within the N. 8 zone of Blow (1969) of latest Early to earliest Middle Miocene age (Ogasawara and Noda, 1996). The Akeyo Fauna differs from the Kurosedani Fauna by lacking the tropical mollusks of the latter (Itoigawa, 1988). It also differs from the Kadonosawa Fauna by lacking the characteristic species of the latter : *Anadara* (*Hataiarca*) *kakehataensis* Hatai and Nisiyama, *Vasticardium ogurai* (Otuka), *Glycydonta itoigawae* (Tsuda), *Tateiwaia tateiwai* (Makiyama), *T. yamanarii* (Makiyama), and *Zeuxis minoensis* (Itoigawa) (Itoigawa, 1988).

A Miocene fauna has been reported from several places in the Kii Peninsula (Mizuno, 1953, 1957 ; Tanai and Mizuno, 1954 ; Katto and Masuda, 1978 ; Katto *et al.*, 1976, 1980 ; Ujihara and Shibata, 1982 ; Chijiwa and Tomita, 1985 ;

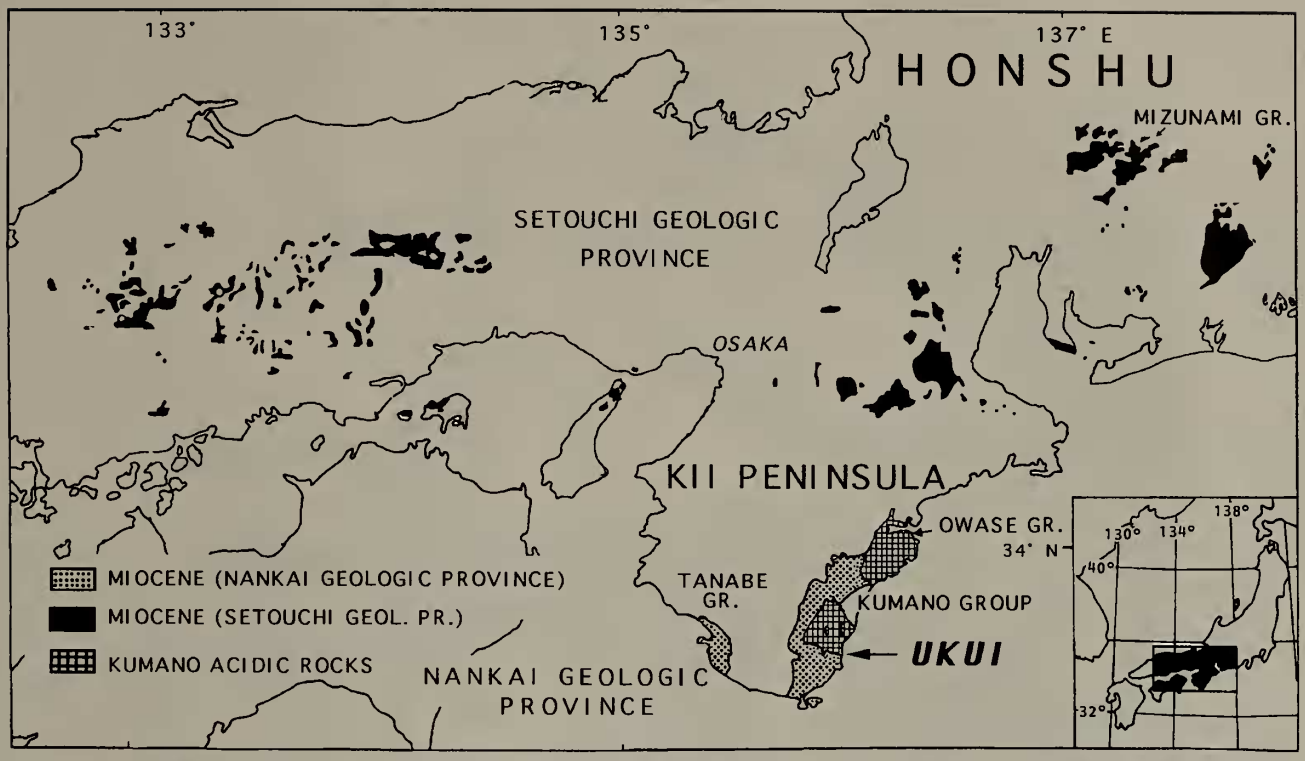


Figure 1. Distribution of the Miocene strata of the Nankai and Setouchi Geologic Provinces, central and southwestern Honshu (*redrawn from*: Itoigawa and Shibata, 1992; Editorial Committee of KINKI, *ed*., Part 6 of Regional Geology of Japan, 1987).

Honda, 1992). However, much data are required to reconstruct the Miocene paleoenvironments in the Nankai Geologic Province.

In 1976 and 1977, one of us (SU) collected several hundred fossil mollusks from a construction site at Ukui Junior High School (Loc. 2; Figures 3, 4), as well as several tens of specimens from an outcrop on a wave-cut terrace at Loc. 7 on Kitsune-jima (Figure 3). Recently, one of us (YH) obtained more specimens from additional localities in the Ukui area. All of these localities are assigned to the Shimosato Formation and together they contain mollusks such as *Saccella miensis* (Araki), *Cyclocardia siogamensis* (Nomura), *Macoma* (*Macoma*) *izurensis* (*Yokoyama*), *Cultellus izumoensis* Yokoyama, *Dosinia* (*Phacosoma*) *nomurai* (Otuka), *Periploma* (*Aelga*) *mitsuganoense* Araki, *Thracia watanabei* Itoigawa and Shibata, *Turritella* (*Hataiella*) *sagai* Kotaka, and *Fulgoraria* (*Musashia*) *yanagidaniensis* Araki (Table 1).

The purpose of this study is to record the molluscan assemblages of the Shimosato Formation, and to describe their characteristic species, including those representative of the Akeyo Fauna. We also wish to clarify the molluscan faunal succession of the Kumano Group of the Nankai Geologic Province of southwestern Japan.

Outline of geology and molluscan fauna

The upper Muro Group (Upper Oligocene to Lower Miocene) of the Shimanto Supergroup and the Shimosato Formation of the Kumano Group are exposed in the Ukui area. The Muro Group consists largely of interbedded gray sandstone and black shale. The Shimosato Formation, on the other hand, is made up of massive, gray, fine- or very fine-grained sandstone, and sandy siltstone. In a wave-cut platform on Kitsune-jima (Loc. 7 in Figure 3), the Shimosato Formation is made up of well-sorted, well-jointed, pale gray, tuffaceous, fine-grained sandstone. The fine-grained sandstone at this locality frequently contains sand-pipes. The Shimosato Formation strikes about N50°E and dips about 10° to 20°SE, and is approximately 200 m thick. Conglomerate of the lowermost Shimosato Formation, which attains a thickness of 30 to 80 cm, rests upon black shale of the uppermost Muro Group with clino-unconformity.

The Kumano Acidic Rocks also crop out in this area. They consist largely of granite porphyry, and intrude into the upper Muro and Kumano Groups. A vertical pyroclastic dike, which is closely related to the Kumano Acidic Rocks (Suzuki, 1976), is exposed in two small cuts at Ukui Junior High School. This dike intrudes into very fine-grained sandstone of the Shimosato Formation, varies in width from approximately 0.5 to 5 m, and trends about N80°E. Figure 3 is a map showing the location of fossil localities in the Shimosato Formation, and Figure 4 shows fossil localities in columnar sections.

Mollusks reported previously from the Shimosato Formation by Ujihara and Shibata (1982) include *Neilonella* cf. *N. isensis* Shibata, *Saccella miensis*, *Portlandia* (*Portlandella*)

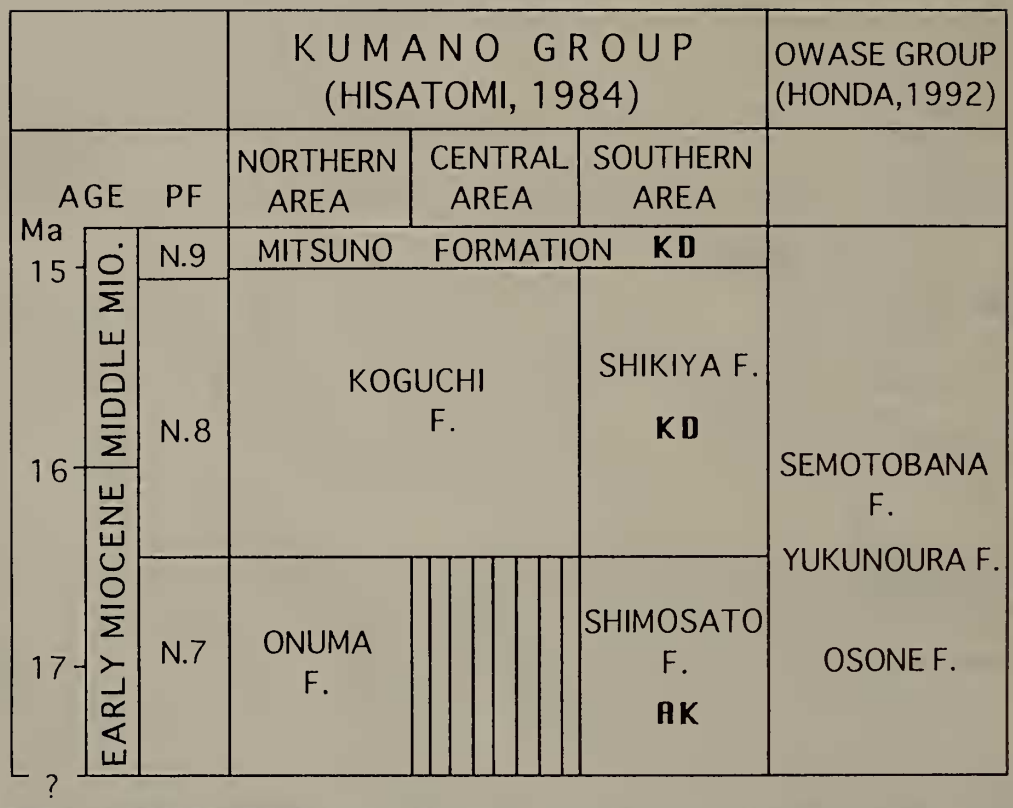


Figure 2. Stratigraphic classification of the Kumano and Owase Groups, southeastern Kii Peninsula. **AK**, occurrence of the molluscan fauna comparable with the Akeyo Fauna; **KD**, occurrences of the assemblages comparable with those of the Kurosedani (Kadonosawa) Fauna. PF, zonation by planktonic foraminifera (Blow, 1969).

watasei (Kanehara), *Yoldia* (*Cnesterium*) sp., *Lucinoma* sp., *Macoma* (*Macoma*) *optiva* (Yokoyama), *Turcicula* (*Turcicula*) *osawanoensis* (Tsuda), *Turritella* (*Turritella*) *kiiensis* (Yokoyama), *Orectospira* sp., and *Euspira mitsuganoensis* Shibata.

Mizuno (1957) reported mollusks in the Shimosato Formation of the Ukui area (Loc. 7 in Figure 3), including *Dosinia* (*Phacosoma*) *nomurai* Otuka and *Turritella* (*Idaella*) *tanaguraensis* Kotaka. Chijiwa and Tomita (1985) noted the following mollusks in the Onuma Formation: *Saccella miensis, Portlandia watasei, Cyclocardia siogamensis, Macoma optiva, M. izurensis, Cultellus izumoensis* Yokoyama, and *Periploma* cf. *P. mitsuganoense*.

The Shikiya Formation contains mollusks such as *Acharax tokunagai* (Yokoyama), *Acilana tokunagai* (Yokoyama), *Conchocele bisecta* (Conrad), *Lucinoma kamenooensis* (Otuka), *Macoma optiva, Turritella sagai*, and *T.* (*Hataiella*) *kadonosawaensis* Otuka (Mizuno, 1953; Tanai and Mizuno, 1954). Katto *et al.* (1976) proposed the Uematsu Formation for the middle part of the Shikiya Formation (Hisatomi and Miyake, 1981), which crops out in the southernmost part of the Kii Peninsula. The Uematsu Formation yields many warm-water mollusks such as *Cucullaea toyamaensis* Tsuda, *Crassatellites pauxillus* (Yokoyama), *Mikadotrochus* sp., and *Conus* (*Chelyconus*) *tokunagai* Otuka (Katto *et al.*, 1976; Katto and Masuda, 1978), in association with larger foraminifers such as *Lepidocyclina* (*Nephrolepidina*) *japonica* (Yabe) and *Miogypsina* sp. (Nishimura and Miyake, 1973).

The lower part of the Mitsuno Formation also contains many warm-water mollusks such as *Glycymeris* (*Veletuceta*) *cisshuensis* Makiyama, *Anadara* (*Anadara*) *kiiensis* Mizuno, *Crassatellites nanus* (Adams and Reeve), and *Conus tokunagai* (Mizuno, 1953; Tanai and Mizuno, 1954). Katto *et al.* (1980) also studied mollusks from the lower part of the Mitsuno Formation (*vide* Saeki and Koto, 1972) and noted the presence of warm-water mollusks such as *Anadara* cf. *A.* (*Anadara*) *ogawai* (Makiyama), *Veremolpa minoensis* (Itoigawa), *Vasticardium ogurai*, and *Paphia hataii* Masuda and Noda.

Honda (1992) studied molluscan fossils of the Owase Group, which crops out on the southeastern margin of the Kii Peninsula to the north of the Kumano Group. The Yukunoura Formation of the Owase Group contains mollusks such as *Acila* sp., *Portlandia* sp., *Cyclocardia siogamensis, Lucinoma* sp., *Macoma optiva, Cultellus otukai* Ogasawara and Tanai, *Periploma* sp., and *Turritella sagai* (Honda, 1992). The assemblages of the Yukunoura Formation resemble those of the Shimosato, Shikiya, and Onuma Formations within the lower and middle parts of the Kumano Group; and those of the Eastern Setouchi Miocene Series in central and

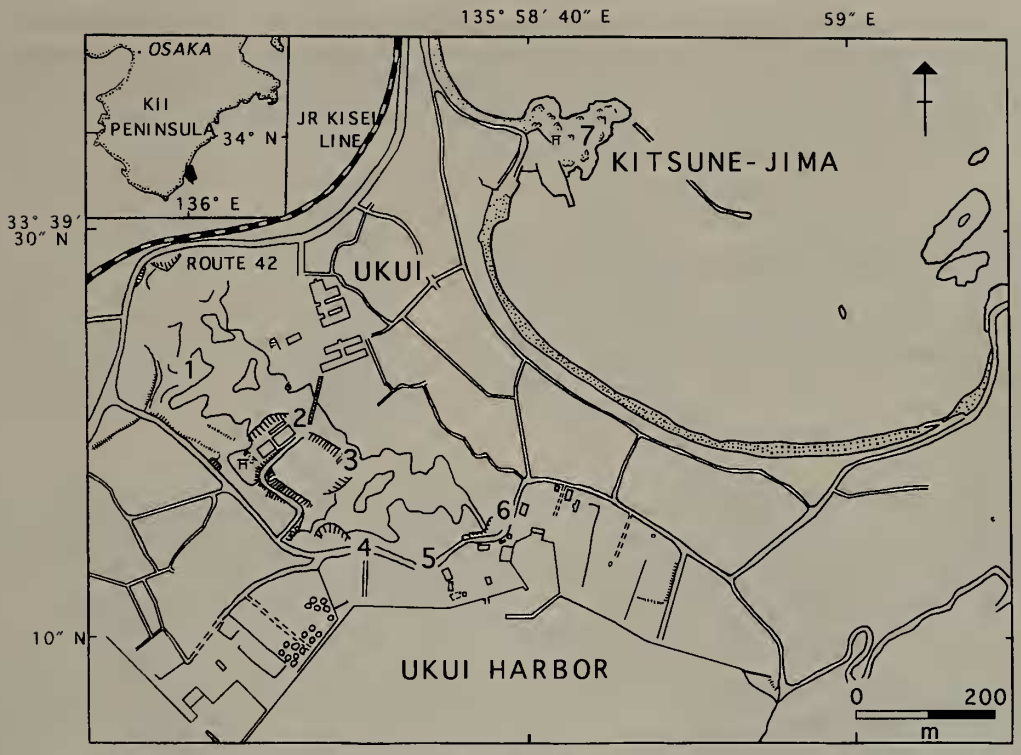


Figure 3. Map showing fossil localities in the Shimosato Formation. 1-7, fossil localities.

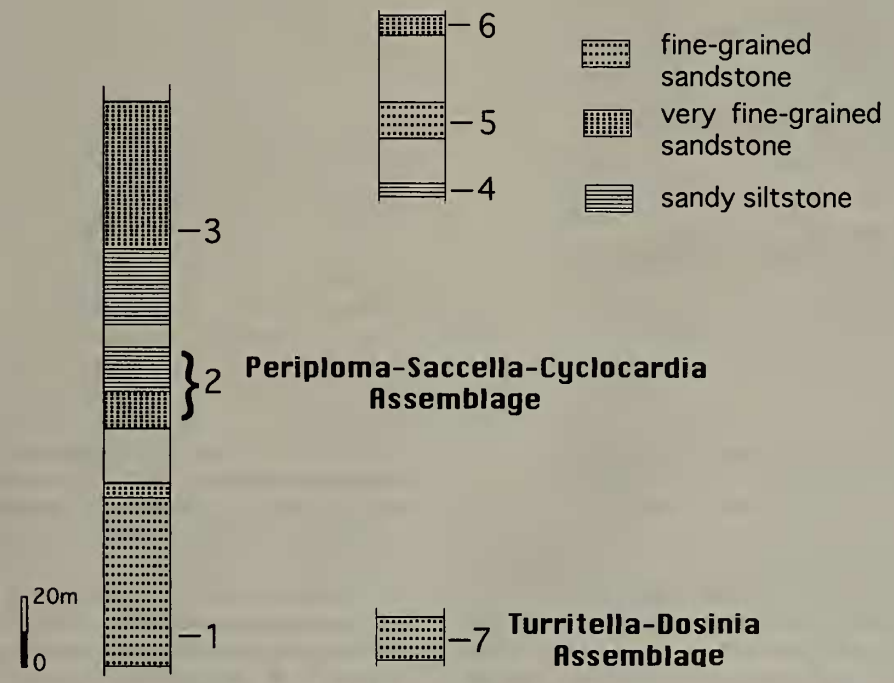


Figure 4. Columnar sections of the Shimosato Formation. 1-7, fossil localities.

Table 1. Occurrences of fossil mollusks in the Shimosato Formation. VA, very abundant (20 or more individuals); A, abundant (10 to 19 individuals); C, common (5 to 9 individuals); F, few (2-4 individuals); R, rare (one individual). One individual is defined herein as consisting of more than half of a separated valve or an articulated pair of bivalves, and more than half of a gastropod specimen. See also Figure 5 and Tables 2, 3.

SPECIES	LOCALITY						
	1	2	3	4	5	6	7
Bivalves:							
Acila cf. *A.* (*Acila*) *submirabilis* Makiyama							R
Acila sp.					R	F	
Ennucula sp.		A					
Saccella miensis (Araki)		VA				R	
Solamen sp.		F					
Septifer? sp.		F					
Chlamys cf. C. *iwamurensis* Itoigawa		R					
Cycladicama sp.		R					
Cyclocardia siogamensis (Nomura)		VA					C
Cyclocardia sp.		C					
Lucinoma sp.		F	R				
Mactra sp.		R					
Macoma (*Macoma*) *izurensis* (Yokoyama)		A					
Angulus cf. *A. kagayamensis* Ogasawara and Tanai		F					
Nitidotellina sp.		R					
Cultellus izumoensis Yokoyama		A					
Disinia (*Phacosoma*) *kawagensis* Araki							F
Dosinia (*Phacosoma*) *nomurai* (Otuka)		R					A
Dosinia sp.		R					C
Paphia sp.		R					
Glauconome sp.		F					
Mya sp.		A					
Anisocorbula sp.		R					
"*Teredo*" sp.			C				
Periploma (*Aelga*) *mitsuganoense* Araki		VA		R			
Periploma (*Aelga*) sp.		VA					
Thracia watanabei Itoigawa and Shibata		F				R	
Thracia sp.					R		
Gastropods:							
Turritella (*Hataiella*) *sagai* Kotaka		A					A
Turritella sp.		R					F
Bittium sp.	F	A					
Euspira sp.		R					
Ancistrolepis sp.		A					
Fulgoraria (*Musashia*) *yanagidaniensis* Araki		C					
Eocylichna sp.		C					

southwestern Honshu.

Molluscan assemblages and environments

Approximately 400 specimens were collected from 7 localities in the Shimosato Formation. These specimens comprise 22 genera and 28 species of bivalves and 6 genera and 7 species of gastropods (Table 1). Mollusks occur sporadically in the fine- and very fine-grained sandstone and sandy siltstone of the Shimosato Formation. Almost all specimens are complete or nearly so, but all except those from Locality 7 lack original shell material. Two molluscan assemblages are recognized herein: the *Periploma-Saccella-Cyclocardia* (Loc. 2) and *Turritella-Dosinia* assemblages (Loc. 7). Mollusks from Localities 1 and 3-6 are not used for recognition of assemblages, because each yielded fewer than 10 specimens. Table 2 summarizes the molluscan assemblages and characteristic and associated species.

The *Periploma-Saccella-Cyclocardia* assemblage

This assemblage occurs in beds of sandy siltstone and overlying very fine-grained sandstone at Locality 2. Both beds are up to about 10 m thick. The assemblage is characterized by the dominant occurrence of *Periploma* (*P.*

Table 2. Molluscan assemblages of the Shimosato Formation. vfs : very fine sandstone ; sdy slt : sandy siltstone ; fs : fine sandstone.

MOLLUSCAN ASSEMBLAGE	CHARACTERISTIC SPECIES	ASSOCIATED SPECIES	LITHOLOGY	LOC.
Periploma-Saccella-Cyclocardia Ass.	*Periploma mitsuganoense* *Saccella miensis* *Cyclocardia siogamensis*	*Ancistrolepis* sp. *Bittium* sp. *Ennucula* sp. *Mya* sp. *Cultellus izumoensis* *T. sagai* *Macoma izurensis*	vfs sdy slt	2
Turritella-Dosinia Assemblage	*Turritella sagai* *Dosinia nomurai* *D. kawagensis*	*C. siogamensis* *Acila* cf. *A. submilabilis*	fs	7

mitsuganoense : Figures 5-12, 5-13, and *P.* sp. : Figure 5-8), *Saccella miensis* (Figure 5-1), and *Cyclocardia* (*C. siogamensis* : Figure 5-14, and *C.* sp.), but also contains *Ancistrolepis* sp., *Bittium* sp., *Ennucula* sp. (Figure 5-2), *Mya* sp. (Figure 5-10), *Cultellus izumoensis* (Figure 5-11), *Turritella sagai* (Figure 5-9), and *Macoma izurensis* (Figure 5-7 ; Table 2). This assemblage typically contains many extant genera that live in upper sublittoral to bathyal depths (N_1-B) off Japan and neighboring countries, including *Saccella*, *Cyclocardia* and *Turritella* (Table 3). However, it also includes *Periploma*, *Ancistrolepis* and *Musashia*, which live in lower sublittoral to bathyal depths (N_3-B, Table 3). Consequently, the *Periploma-Saccella-Cyclocardia* assemblage is inferred to represent a lower sublittoral to bathyal environment.

Comparison : The Onuma Formation of the Kumano Group contains a number of species known from this assemblage, including *Saccella miensis*, *Cyclocardia siogamensis*, *Macoma izurensis*, and *Cultellus izumoensis* (Chijiwa and Tomita, 1985). This assemblage is therefore correlative with those of the Onuma Formation, which represent lower sublittoral environments (Chijiwa and Tomita, 1985).

In addition, the *Periploma-Saccella-Cyclocardia* assemblage contains many species in common with the *Periploma-Acila* and *Macoma-Lucinoma* assemblages in the Eastern Setouchi Miocene Series of central and southwestern Honshu, including *Saccella miensis*, *Periploma* sp., *M. izurensis*, *Cultellus izumoensis*, and *Cyclocardia siogamensis* (Shibata, 1978). This assemblage is therefore also correlative with the *Periploma-Acila* and *Macoma-Lucinoma* assemblages, which represent upper sublittoral and sublittoral environments, respectively (Shibata, 1978).

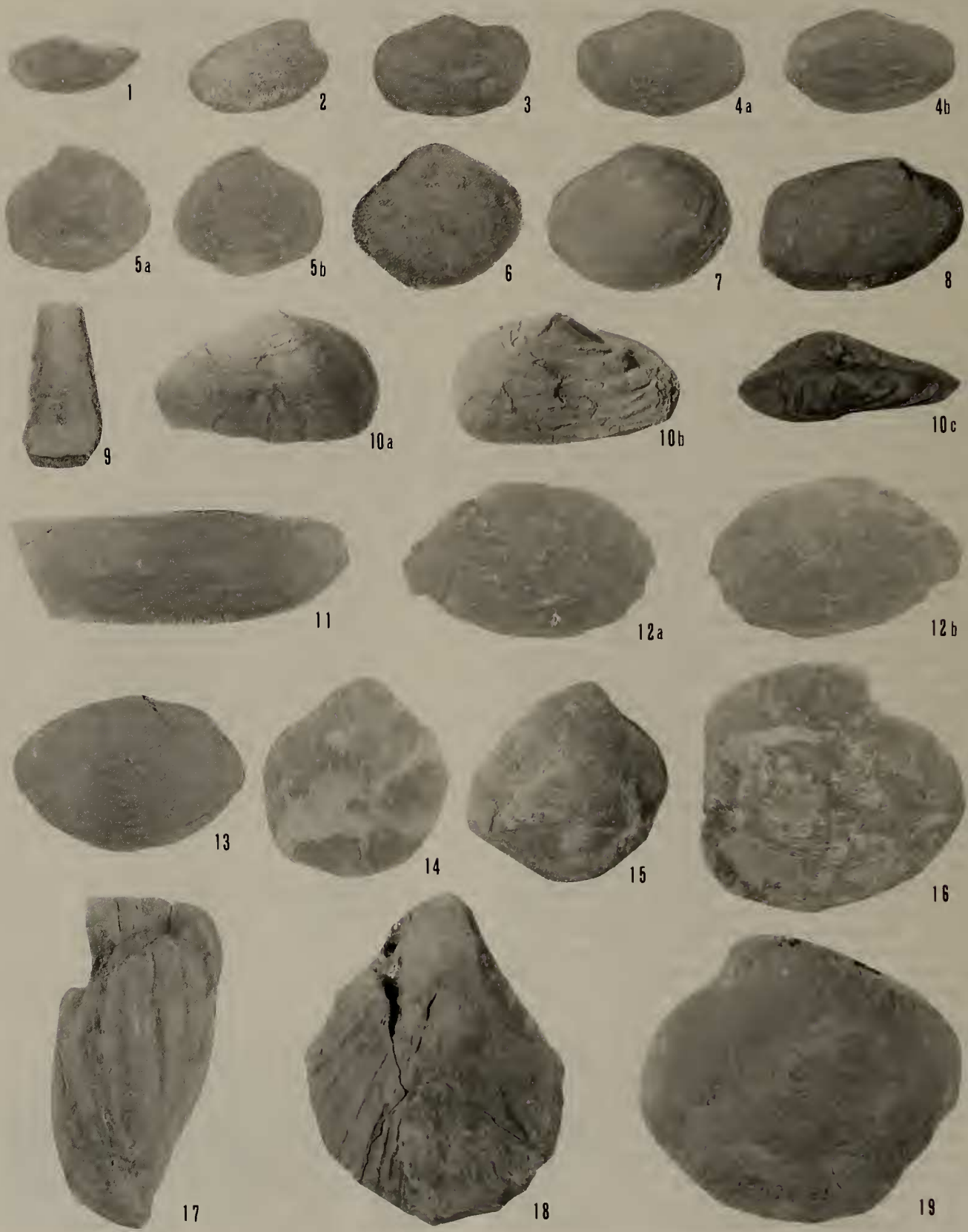
The *Turritella-Dosinia* assemblage

This assemblage occurs in gray, fine-grained sandstone at Locality 7 and is characterized by the dominant occurrence of *Turritella* (*T. sagai* : Figure 5-9, and *T.* sp.) and *Dosinia* (*D. nomurai* : Figures 5-15, 5-19, *D. kawagensis* : Figure 5-16, and *D.* sp.) (Table 2). *Cyclocardia siogamensis* and *Acila* cf. *A. submirabilis* (Figure 5-6) are also present in this assemblage (Table 2). The presence of many intact specimens in this assemblage implies that there was little or no post-mortem transportation. Modern *Turritella*, *Cyclocardia* and *Acila* species live in upper sublittoral to bathyal depths (N_1 (N_2)-B), and *Dosinia* (*Phacosoma*) dwells in the tidal to lower sublittoral zone (T-N_4) (Table 3). The *Turritella-Dosinia* assemblage is therefore inferred to represent a sublittoral environment.

Table 3. Modern bathymetric distribution of extant northwestern Pacific bivalves and gastropods in the Shimosato molluscan fauna (Higo and Goto, 1993). Depth ; T, tidal zone ; N_1, low-water line to 30 m ; N_2, 30-60 m ; N_3, 60-120 m ; N_4, 120-200 m ; B, over 200 m deep (Taki and Oyama, 1954, *partly revised*).

GENERA (SUBGENERA)	DEPTH T	N_1	N_2	N_3	N_4	B
Acila (Acila)						
Ennucula						
Saccella						
Solamen						
Chlamys						
Cycladicama						
Cyclocardia						
Lucinoma						
Mactra						
Macoma						
Angulus						
Nitidotellina						
Phacosoma						
Paphia						
Glauconome						
Mya						
Anisocorbula						
Periploma						
Thracia						
Turritella						
Bittium						
Euspira						
Ancistrolepis						
Musashia						
Eocylichna						

Comparison : This assemblage contains *Turritella sagai*


1
2
3
4a
4b
5a
5b
6
7
8
9
10a
10b
10c
11
12a
12b
13
14
15
16
17
18
19

and *Dosinia nomurai* in common with the *Turritella-Lucinoma* assemblage of the Tomikusa Group (upper Lower Miocene) in the Eastern Setouchi Miocene Series of central Honshu (Shibata, 1978). This assemblage is therefore correlative with the *Turritella-Lucinoma* assemblage, which represents an upper sublittoral environment (Shibata, 1978).

Discussion

Honda (1992) noted that two types of molluscan assemblage are present in the Kumano and Owase Groups. The first type has been recorded from the Shimosato, Shikiya, and Onuma Formations within the lower and middle parts of the Kumano Group (Mizuno, 1953 ; Tanai and Mizuno, 1954 ; Ujihara and Shibata, 1982 ; Chijiwa and Tomita, 1985) ; and the Yukunoura Formation of the Owase Group (Honda, 1992). The type is characterized by *Portlandia watasei*, *Cyclocardia siogamensis*, *Lucinoma* sp., *Macoma optiva* (*M. izurensis*), *Cultellus izumoensis*, and *Turritella sagai* (*T. kadonosawaensis*, *T. shataii*, *T. kiiensis*).

The *Periploma-Saccella-Cyclocardia* and *Turritella-Dosinia* assemblages of the Shimosato Formation contain many species in common with those of the first type, including *Cyclocardia siogamensis*, *Macoma izurensis*, *Cultellus izumoensis*, and *Turritella sagai* (Table 2). Both assemblages therefore belong to the first type. In addition, the Shimosato Formation contains *Dosinia kawagensis*, *Thracia watanabei*, *Turritella sagai*, and *Fulgoraria yanagidaniensis* (Table 1), which characterize the fauna of the Akeyo Formation. The fauna of the Shimosato Formation is therefore comparable with the Akeyo Fauna of late Early Miocene age (ca. 18 to 16 Ma ; Itoigawa, 1987, 1988) (Figure 2).

On the other hand, the second type of molluscan assemblage has been reported from the middle part of the Shikiya and the lower part of the Mitsuno Formation within the middle and upper parts of the Kumano Group (Mizuno, 1953 ; Tanai and Mizuno, 1954 ; Katto and Masuda, 1978 ; Katto *et al.*, 1980). The type is characterized by many warm-water mollusks such as *Anadara* cf. *A. ogawai*, *Cucullaea toyamaensis*, *Crassatellites pauxillus*, *C. nanus*, *Vasticardium ogurai*, *Mikadotrochus* sp., and *Conus tokunagai*.

Among these species, *Cucullaea toyamaensis* and *Conus tokunagai* characterize the Kurosedani Fauna of southwestern Japan. *Conus tokunagai* is also characteristic in the Kadonosawa Fauna of northern Japan. The middle part of the Shikiya Formation yields *Cucullaea toyamaensis* and *Conus tokunagai* (Katto and Masuda, 1978), in association with larger foraminifers such as *Lepidocyclina japonica* and *Miogypsina* sp. (Nishimura and Miyake, 1973). In addition, *Conus tokunagai* has been reported from the lower part of the Mitsuno Formation (Mizuno, 1953 ; Tanai and Mizuno, 1954 ; Katto *et al.*, 1980).

Accordingly, the assemblages of the middle part of the Shikiya Formation and the lower part of the Mitsuno Formation are comparable with those of the Kurosedani (Kadonosawa) Fauna (Figure 2). The occurrence of the Kurosedani (Kadonosawa) Fauna corresponds to the warm marine climatic episode during the latest Early to earliest Middle Miocene period (ca. 16-15 Ma) (Chinzei, 1986).

Such a different stratigraphic occurrence of the molluscan assemblages suggests a warming of climate and not merely a change in the sedimentary environment. The warming of climate is also recognized in the transition from the subtropical Akeyo to tropical Kurosedani Fauna in the Mizunami Group of the Eastern Setouchi Miocene Series (Itoigawa, 1988, 1989).

A similar scenario has also been proposed for another taxonomic group in the Kumano Group. For instance, Nishimura and Miyake (1973) reported larger foraminifers such as *Lepidocyclina japonica* and *Miogypsina* sp. from the middle part of the Shikiya Formation. Using planktonic foraminifers, Ibaraki (1990) assigned the *Lepidocyclina-Miogypsina-bearing* horizon to the N8.b zone of Blow (1969). From the occurrence of *Orbulina universa* d'Orbigny (Ikebe *et al.*, 1975), the uppermost part of the Shikiya Formation and the Mitsuno Formation correlate with the N.9 zone of Blow (1969) (Hisatomi, 1987) (Figure 2).

As was discussed in the aforementioned lines, the molluscan assemblages of the lower part of the Mitsuno Formation (Mizuno, 1953 ; Tanai and Mizuno, 1954 ; Katto *et al.*, 1980) are comparable with those of the Kurosedani (Kadonosawa) Fauna. The fauna, however, is restricted within the N. 8 zone of Blow (1969) of latest Early to earliest Middle Miocene age (Ogasawara and Noda, 1996). Further studies are needed to clarify the molluscan faunal succession of the Kumano Group of the Nankai Geologic Province of southwestern Japan.

Summary of faunal discussion

1) The *Periploma-Saccella-Cyclocardia* and *Turritella-Dosinia* assemblages of the Shimosato Formation are inferred to represent lower sublittoral to bathyal and sublittoral environments, respectively.

2) The fauna of the Shimosato Formation is comparable with the subtropical Akeyo Fauna of late Early Miocene age,

Figure 5. **1.** *Saccella miensis* (Araki). Loc. 2, MES* 1015. **2.** *Ennucula* sp. x2, Loc. 2, MES 1016. **3, 5a-b.** *Thracia watanabei* Itoigawa and Shibata. 3 ; Loc. 2, MES 1017. 5a-b ; Loc. 6, MES 1018. **4a-b.** *Glauconome* sp. Loc. 2, MES 1019. **6.** *Acila* cf. *A.* (*Acila*) *submirabilis* Makiyama. x1.5, Loc. 7, MES 1020. **7.** *Macoma* (*Macoma*) *izurensis* (Yokoyama). Loc. 2, MES 1021. **8.** *Periploma* (*Aelga*) sp. Loc. 2, MES 1022. **9.** *Turritella* (*Hataiella*) *sagai* Kotaka. Loc. 7, MES 1023. **10a-c.** *Mya* sp. Loc. 2, MES 1024. **11.** *Cultellus izumoensis* Yokoyama. Loc. 2, MES 1025. **12a-b, 13.** *Periploma* (*Aelga*) *mitsuganoense* Araki. 12a-b. Loc. 2, MES 1026. 13 ; Loc. 2, MES 1027. **14.** *Cyclocardia siogamensis* (Nomura). x1.5, Loc. 2, MES 1028. **15, 19.** *Dosinia* (*Phacosoma*) *nomurai* (Otuka). 15 ; Loc. 2, MES 1029. 19 ; Loc. 7, MES 1030. **16.** *Dosinia* (*Phacosoma*) *kawagensis* Araki. Loc. 7, MES 1031. **17.** *Fulgoraria* (*Musashia*) *yanagidaniensis* Araki. Loc. 2, MES 1032. **18.** *Chlamys* cf. *C. iwamurensis* Itoigawa. Loc. 2, MES 1033. All figures natural size unless otherwise stated. *Abbreviation for the Department of Earth Sciences, Faculty of Education, Mie University.

based on the occurrence of diagnostic species such as *Dosinia kawagensis, Thracia watanabei, Turritella sagai*, and *Fulgoraria yanagidaniensis*.

3) The assemblages of the middle part of the Shikiya Formation and the lower part of the Mitsuno Formation are comparable with those of the tropical Kurosedani (subtropical Kadonosawa) Fauna of latest Early to earliest Middle Miocene age.

Systematic notes on some important species

Phylum Mollusca
Class Bivalvia
Family Veneridae
Subfamily Dosiniinae
Genus ***Dosinia*** Scopoli, 1777
Subgenus ***Phacosoma*** Jukes-Browne, 1912

Dosinia* (*Phacosoma*) *kawagensis Araki, 1960

Figure 5-16

Dosinia nomurai Otuka ; Itoigawa, 1956, pl. 2, fig. 3 (*non* Otuka, 1934).
Dosinia japonica kawagensis Araki, 1960, p. 95, pl. 7, fig. 3.
Dosinia (*Phacosoma*) *kawagensis* Araki ; Masuda, 1963, p. 22, pl. 4, figs. 1-8 (fig. 1, reproduced from Araki, 1960) ; Yoon, 1979, p. 15, pl. 2, figs. 7, 9, 10 ; Matsubara, 1995b, p. 330, pl. 4, figs. 9-11.
Dosinia kawagensis Araki ; Hayashi and Miura, 1973, pl. 2, fig. 12 ; Hayashi, 1973, pl. 1, figs. 2, 3 ; Ishida *et al.*, 1980, pl. 3, fig. 12.
Dosinorbis kawagensis (Araki) ; Itoigawa *in* Itoigawa *et al.*, 1974, p. 87, pl. 23, figs. 1-6.
Phacosoma kawagensis (Araki) ; Itoigawa *et al.*, 1981 (1982, p. 80), pl. 14, figs. 6a-b ; Shibata and Ina, 1983, p. 48, pl. 5, fig. 12 ; Itoigawa and Shibata, 1986, pl. 16, fig. 13 ; Muramatsu, 1992, pl. 49, fig. 10.
Dosinia (*Phacosoma*) *chikuzenensis nomurai* Otuka ; Hayashi, 1988, p. 5, pl. 1, figs. 2, 3 (reproduced from illustration of *Dosinia kawagensis* in Hayashi (1973)).

Remarks.—Two incomplete closed valves were obtained from fine-grained sandstone of the Shimosato Formation. The present species was originally described by Araki (1960) (as *D. japonica kawagensis*) from the Kaisekizan Formation (upper Lower Miocene ; *vide* Yoshida, 1991 ; Shibata, 1967) of the Ichishi Group, Mie Prefecture, southwestern Honshu. Itoigawa (1956) had earlier cited "*D. nomurai*" from the Tsuzuki Group (upper Lower Miocene) of Kyoto Prefecture, but Masuda (1963) later assigned this occurrence to *D. kawagensis*.

The present species resembles *D.* (*Phacosoma*) *nomurai* Otuka, 1934, which was originally described from the Kadonosawa Formation (uppermost Lower to lowermost Middle Miocene ; Irizuki and Matsubara, 1994) of Iwate Prefecture, northeastern Honshu. However, *D.* (*P.*) *kawagensis* differs by having a more anteriorly expanded anterodorsal margin. The present species also resembles *D.* (*P.*) *japonica* (Reeve), which is living in Japan, but differs from the latter by having a smaller and somewhat more inequilateral shell.

The present species has also been recorded from the upper Lower to lowermost Middle Miocene formations of Honshu and Korea. These include the Akeyo Formation of the Mizunami Group, and other strata of the Eastern Setouchi Miocene Series in central and southwestern Honshu (Itoigawa *et al.*, 1981) ; the Shiode, Ajiri, and Yotsuyaku Formations of northeastern Honshu (Masuda, 1963 ; Matsubara, 1995b) ; and the Sinhyeon Formation of Korea (Yoon, 1979).

Occurrence.—As characteristic species of *Turritella-Dosinia* ass. at Locality 7.

Family Periplomatidae
Genus ***Periploma*** Schumacher, 1817
Subgenus ***Aelga*** Slodkewitsch, 1935

Periploma* (*Aelga*) *mitsuganoense Araki, 1959

Figures 5-12a-b, 13

Periploma mitsuganoense Araki, 1959, p. 163, pl. 18, figs. 2a-b ; Araki, 1960, p. 85, pl. 5, figs. 13a-b (reproduced from Araki, 1959) ; Shibata in Itoigawa *et al.*, 1974, p. 108, pl. 34, figs. 12-17 ; Ishida *et al.*, 1980, pl. 4, fig. 21 ; Itoigawa *et al.*, 1981 (1982, p. 115), pl. 22, figs. 14a-b ; Itoigawa and Shibata, 1986, pl. 17, fig. 13 ; *non* Hayashi, 1973, pl. 5, fig. 1.

Remarks.—Approximately 80 slightly deformed specimens were collected from sandy siltstone of the Shimosato Formation. Araki (1959) based this species on specimens from the Kaisekizan Formation (upper Lower Miocene) of the Ichishi Group, Mie Prefecture, southwestern Honshu. It closely resembles *Periploma* (*Aelga*) *besshoense* (Yokoyama, 1924), which was originally described from the Asagai Formation (Lower Oligocene) of the Joban coal field, northeastern Honshu, but is distinguished from the latter in having a more inequilateral shell. *Periploma owasense* Suzuki (1934, p. 348, text-fig. 4), described from the Owase Group (upper Lower to lowermost Middle Miocene) of Mie Prefecture, southeastern Kii Peninsula, is allocated here to *Periploma* sp. indet., owing to the poor preservation of the specimen. *Periploma mitsuganoense* has also been recorded from the Akeyo Formation of the Mizunami Group, and other strata of the Eastern Setouchi Miocene Series (Itoigawa *et al.*, 1981).

Occurrence.—As characteristic species of *Periploma-Saccella-Cyclocardia* ass. at Locality 2 and also from Loc. 4.

Family Thraciidae
Genus ***Thracia*** Leach, 1824

Thracia watanabei Itoigawa and Shibata, 1975

Figures 5-3, 5a-b

Thracia sp. (n. sp.) ; Itoigawa *in* Itoigawa *et al.*, 1974, p. 108, pl. 34, figs. 10-11.
Thracia watanabei Itoigawa and Shibata, 1975, p. 31, pl. 8, figs. 21-24 ; Itoigawa *et al.*, 1981 (1982, p. 116), pl. 22, fig. 16.

Remarks.—Only four specimens were obtained from gray, very fine-grained sandstone at two localities in the Shimosato Formation. The present species was proposed by Itoigawa and Shibata (1975) from the Yamanouchi Mem-

ber of the Akeyo Formation of the Mizunami Group. *Thracia watanabei* has also been recorded from the Tomikusa, Iwamura and Ayugawa Groups of the Eastern Setouchi Miocene Series in central and southwestern Honshu (Itoigawa *et al.*, 1981).

Occurrence.—Localities 2, 6.

Class Gastropoda
Family Turritellidae
Genus ***Turritella*** Lamarck, 1799
Subgenus ***Hataiella*** Kotaka, 1959

Turritella* (*Hataiella*) *sagai Kotaka, 1951

Figure 5-9

Turritella s-hataii sagai Kotaka, 1951, p. 87, pl. 12, figs. 13-17.
Turritella (*Hataiella*) *sagai* Kotaka; Kotaka, 1959, p. 89, pl. 9, figs. 6-8, 10, 12, 18; Yoon, 1979, p. 21, pl. 5, fig. 11; Marincovich and Kase, 1986, p. 61, pl. 2, figs. F-H (in part); Honda, 1992, pl. 58, fig. 8.
Non Turritella (*Hataiella*) *sagai* Kotaka; Marincovich and Kase, 1986, pl. 2, figs. A-E (in part); Marincovich, 1988, p. 15, pl. 3, figs. 3, 5-9 (3, 5-7, 9; reproduced from Marincovich and Kase, 1986, p. 61, pl. 2, figs. A-E); Zhidkova and Sal'nikov, *eds*., 1992, p. 248, pl. 46, figs. 3a-b.
Turritella sagai Kotaka; Shibata *in* Itoigawa *et al*., 1974, p. 132, pl. 40, figs. 11, 12; Ishida *et al*., 1980, pl. 5, figs. 10, 11; Itoigawa *et al*., 1981 (1982, p. 164), pl. 28, figs. 13-14; Itoigawa and Shibata, 1986, pl. 17, fig. 2; Muramatsu, 1992, pl. 50, fig. 9.

Remarks.—A total of 26 specimens are to hand. The present species was originally described by Kotaka (1951, p. 87, pl. 12, figs. 13-17) from the Togari Member of the Akeyo Formation of the Mizunami Group. As noted by Kotaka (1951), *T.* (*Hataiella*) *sagai* resembles *T.* (*H.*) *shataii* Nomura, originally described from the "Shiogama" Formation (Lower Miocene; Ishii *et al*., 1982, p. 14, 20) of Miyagi Prefecture, northeastern Honshu. The present species also resembles *T.* (*H.*) *belogolovaensis* Ilyina, originally described from the Kuluven Formation (Lower Miocene) of western Kamchatka (*vide* Titova, 1994, p. 7), but it differs from the latter in having a more slender shell.

Marincovich and Kase (1986, p. 61, pl. 2, figs. A-H) cited *Turritella sagai* from the Bear Lake Formation (lowermost Middle Miocene, in part) of southwestern Alaska (figs. A-E), and the Akebihara Sandstone of the Ayugawa Group (upper Lower Miocene) of southwestern Honshu (figs. F-H). Specimens from the Bear Lake Formation are assigned here to *T. belogolovaensis*, as was done by Titova (1994). Zhidkova and Sal'nikov, *eds*. (1992, p. 248, pl. 46, figs. 3a-b) cited *T.* (*H.*) *sagai* from the Neveliskaya Formation (Lower Miocene) of southern Sakhalin, and this occurrence is also assigned here to *T. belogolovaensis*.

Turritella sagai has been recorded from the Akeyo Formation of the Mizunami Group and other strata of the Eastern Setouchi Miocene Series (Itoigawa *et al*., 1981), and the Hwabongri Formation (lower Middle Miocene) of Korea (Yoon, 1979).

Occurrence.—As characteristic species of *Turritella-Dosinia* ass. at Loc. 7, and as associated species of *Periploma-Saccella-Cyclocardia* ass. at Loc. 2.

Family Volutidae
Subfamily Fulgorariinae
Genus ***Fulgoraria*** Schumacher, 1817
Subgenus ***Musashia*** Hayashi, 1960

Fulgoraria* (*Musashia*) *yanagidaniensis Araki, 1959
Figure 5-17

Fulgoraria hirasei yanagidaniensis Araki, 1959, p. 165, pl. 18, fig. 6; Araki, 1960, p. 104, pl. 8, fig. 5 (reproduced from Araki, 1959).
Musashia (*Neopsephaea*?) *yanagidaniensis* (Araki); Shikama, 1967, p. 115, text-fig. 20, pl. 13, figs. 5-8.
Musashia (*Neopsephaea*) *yanagidaniensis* (Araki); Shikama, 1967, pl. 14, fig. 1 (same specimen as Shikama, 1967, pl. 13, fig. 8).
Musashia yanagidaniensis (Araki); Hayashi, 1973, pl. 3, fig. 8; Shibata and Ina, 1983, p. 62, pl. 9, fig. 6.
Psephaea? *yanagidaniensis* (Araki); Shibata *in* Itoigawa *et al*., 1974, p. 167, pl. 51, figs. 1-3, pl. 52, figs. 1, 2, pl. 53, figs. 1-3, pl. 54, figs. 5a-c.
Fulgoraria yanagidaniensis (Araki); Ishida *et al*., 1980, pl. 6, figs. 34a-b.
Musashia (s. s.) *yanagidaniensis* (Araki); Itoigawa *et al*., 1981.
Musashia? *yanagidaniensis* (Araki); Itoigawa *et al*., 1982, p. 239, pl. 40, figs. 1-2.
Fulgoraria (*Psephaea*?) cf. *ashiyaensis* Shikama; Hayashi, 1988, p. 7, pl. 3, fig. 8 (reproduced from *Musashia yanagidaniensis*; Hayashi, 1973).

Remarks.—Seven specimens were collected from gray, very fine-grained sandstone at one locality in the Shimosato Formation. Araki (1959) proposed the present species under the name of *Fulgoraria hirasei yanagidaniensis* from the Kaisekizan Formation (upper Lower Miocene) of the Ichishi Group. The present species has also been recorded from the Akeyo Formation of the Mizunami Group and other strata of the Eastern Setouchi Miocene Series (Itoigawa *et al*., 1981).

Occurrence.—Locality 2.

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